A New Class of Radio Halo

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Introduction: Galaxy clusters are the largest gravitationally bound systems in the Universe and their interactions via collisions and mergers are the most energetic events since the Big Bang. The gas in these systems is mixed with magnetic fields and relativistic particles, creating diffuse, megaparsec-scale synchrotron radiation at the cluster center which can be observed at radio wavelengths. Currently detected in only a fraction of known interacting clusters, this emission is called a radio "halo."

A team of scientists, including astronomers from the Naval Research Laboratory, has detected a radio halo at long wavelengths in a colliding, massive galaxy cluster; surprisingly, it is not detected at the shorter wavelengths where these objects are typically seen. The discovery implies that existing radio telescopes have missed a large population of these colliding objects; in fact it suggests a new class of radio halos. These halos could be uniquely studied at long radio wavelengths, using new, more sensitive telescopes currently being built, such as the NRL-conceived Long Wavelength Array (LWA).

Abell 521 Data: Abell 521 is a massive, X-ray luminous cluster involved in multiple ongoing mergers (Fig. 3). We have detected a long-wavelength (λ = 125 cm, 92 cm, 49 cm) radio halo associated with this cluster using the Giant Metrewave Radiotelescope (GMRT) in India. Observations using the National Science Foundation's Very Large Array (VLA) radio telescope at the shorter wavelengths typically used to observe radio halos (λ = 21 cm) were unable to detect it. Observations using the VLA at longer wavelengths (λ = 4 m; a system partly developed at NRL) lacked the sensitivity to detect the halo at its anticipated strength but were able to place a limit on the long-wavelength flux.

Scientific Importance: There are two theories for how the electrons are accelerated to produce radio halos. The turbulent re-acceleration theory posits that older electrons are re-accelerated by merger-induced turbulence to the energies necessary to produce the observed radio-synchrotron emission in the relatively weak cluster magnetic fields. The secondary injection theory generates the necessary energy from collisions between relativistic cluster protons and thermal particles in the intergalactic medium. Previous studies of radio halos have been unable to distinguish which mechanism is correct.

The multi-wavelength observations of Abell 521 (4 m, 125 cm, 92 cm, 49 cm, 21 cm) allow us to reconstruct its radio spectrum. The resulting spectrum has an extremely steep slope, implying a high-frequency (short-wavelength) cutoff in the emission. Such a result is inconsistent with a secondary origin of the relativistic electrons, but instead supports the theory that they were accelerated by turbulent acceleration.

This is the first observational evidence that has enabled us to distinguish between the two theoretical creation mechanisms for radio halos. It represents a step forward in our understanding of interacting galaxy clusters, which in turn play an important role in studies of dark matter and dark energy. If we take Abell 521 as a prototype system, it also suggests that many radio halos in the Universe should emit mainly at long wavelengths.

Importance to NRL Program: In order to properly analyze the radio data, we implemented and improved algorithms for long-wavelength, widefield imaging, radio frequency interference-excision, and ionospheric modeling, all goals of our ongoing 6.1 Advanced Research Initiative, Large Array HF/VHF Imaging. In addition to addressing these technical challenges and refining the software for addressing them, the basic research involved has helped to identify a new class of objects in the Universe that can be uniquely studied with planned instruments such as the LWA.

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References

[1] G. Brunetti et al., "A Low-frequency Radio Halo Associated with a Cluster of Galaxies," *Nature* **455**, 944–947, October 16, 2008.

FIGURE 3
Superimposed false-color images of the galaxy cluster Abell 521. The blue color represents hot gas typical of many galaxy clusters detected by the Chandra X-ray Observatory. The shape of the X-ray emission indicates that the cluster has undergone a recent collision or "merger event" that could generate turbulent waves. The red represents radio emission at 125 cm wavelength. The bright radio source on the lower left periphery of the X-ray gas is a separate source. The region of radio halo emission generated by turbulent waves is located at the center of the cluster, where the colors overlap.